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Learning from positive deviants in fisheries

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Abstract

Despite progress in the management of assessed fish populations, many countries lag behind international commitments to restore overexploited stocks to healthy abundances. Here we use a mixed-methods positive deviance approach, also known as 'bright spot' analysis, to understand what drives the successful governance of exploited species by learning from positive outliers, or 'deviants'. We use Canada as a case study, identifying factors driving the abundance of 230 commercially exploited fish and invertebrate populations, of which only 28% were classified at healthy abundance in 2022. We first applied a generalized linear model to test how diverse socio-ecological fishery attributes relate to stock health. We found healthier stocks are positively and significantly correlated with certain management regions, more selective gears, eco-certification, and high fishery value. Counterintuitively, healthier stocks were also associated with high inherent fishing vulnerability and the absence of reference points. We then used fishery expert surveys and interviews to investigate the social and institutional characteristics of stocks healthier than expected, given their circumstances. We found that fisheries targeting these positive outliers have lower conflict among users, balanced stakeholder involvement in data collection and decision-making, and improved accounting of mortality sources. Lessons from these positive deviants can be applied to improve underperforming management systems that are struggling to reverse overexploitation in Canada and elsewhere. More generally, we suggest that a positive deviance approach, already used in public health, could be a promising tool to learn about successful fisheries management interventions, and the diverse actors responsible for ensuring these interventions are successful.

KEYWORDS
Canadian fisheries, commercial fisheries, fisheries management, positive deviance analysis

1 | INTRODUCTION

Global seafood consumption has risen steadily since the 1950s (FAO, 2022), and 'blue foods' – marine life from both capture fisheries and aquaculture – are considered important for meeting the nutritional needs and dietary preferences of communities, countries, and cultures (Crona et al., 2023; Tigchelaar et al., 2022). Indeed, ending overfishing is a prerequisite for over half of Sustainable Development Goal (SDG) targets connected to SDG 14: Life Below Water (Singh et al., 2018), and equitable access to marine resources is considered a necessity for a viable blue economy (Cisneros-Montemayor et al., 2021). Recent estimates suggest 52%–57% of the world's scientifically assessed fish stocks are currently at biologically sustainable levels of abundance (i.e., $B > B_{MSY}$), with a wide range of outcomes within and across regions (Britten et al., 2021; Hilborn et al., 2020).

Here we focus on Canada, a resource-rich country with the world's longest coastline and seventh largest exclusive economic zone (EEZ). Commercial fishers in Canada currently land ~720,000 mt of seafood annually (Figure 1a) yet Schijns and Rangeley (2022) report that only 29% of all stocks in Canada are at 'healthy' levels of abundance (i.e., $B \geq 0.8B_{MSY}$; see Table S1 for definitions of stock health relevant to this study). Concerningly, 17% of stocks are in the critical zone (i.e., $B \leq 0.4B_{MSY}$), and the status of 42% of all stocks is uncertain due to insufficient data collection and monitoring (Figure 1b). These statistics are surprising since Canada has a comparatively well-funded science and management sector that should produce better outcomes. Indeed, strong fisheries management is considered a touchstone for many high-income maritime nations (Hilborn & Ovando, 2014), and countries such as New Zealand, the U.S.A., and Australia have all implemented tightly regulated harvest strategies for their fisheries, which have guided successful rebuilding of many depleted stocks in recent decades (Hilborn et al., 2020).

1.1 | Challenges facing Canadian fisheries

The collapse of Canada's northern Atlantic cod (*Gadus morhua*, Gadidae) stock in the 1990s became a global icon for overfishing, as well as the economic and societal costs of mismanagement (Hutchings & Myers, 1994). Nearly three decades later, significant barriers persist in the ability of Canada's fisheries management agency (Fisheries and Oceans Canada; DFO) to implement precautionary science-based harvest strategies for many stocks (Archibald et al., 2021a; Hutchings et al., 2019) and rebuild those that are now depleted (Levesque et al., 2021). This implementation gap has been attributed to the overarching conflict of DFO's dual mandate to support economic growth and conserve the environment (Hutchings, 2022). Other perceived barriers include an opaque and slow policy process (Archibald et al., 2021b) and the discretionary power granted to the Fisheries Minister, which includes a unliteral decision-making capacity that can supersede advice provided by DFO scientists to set catch limits (Hutchings et al., 2019).

Furthermore, conflict over fishery access between Indigenous and non-Indigenous fishers, as well as inshore and offshore fleets, has been prevalent in Canadian fisheries for decades (Bilefsky, 2020; Charles, 1992; Mitchell et al., 1984). Facing these intersectional challenges – and the relatively weak state of the country's fish stocks – the Canadian government committed to managing all marine life sustainably by 2025 (DFO, 2020). This commitment is in keeping with the country's recently revised *Fisheries Act*, which formalizes the need for harvest strategies as part of a precautionary approach to management, as well as additional regulations implemented in 2022 (SOR/2022-73). The *Fisheries Act*'s Fish Stocks Provisions regulations include a requirement to ensure major fish stocks are maintained at abundances that promote sustainability and, where needed, to designate a rebuilding plan for stocks in the critical zone within two years such that 'the level of fishing permitted, if any, is consistent with the intent of rebuilding the stock above the [Limit Reference Point]' (Government of Canada, 2022). Notably, the Fish Stocks Provisions only applies to 30 stocks at present, 16 of which are listed as below their Limit Reference Point (DFO, 2022b).

Given Canada's legal and political commitments, and broader international targets (e.g., SDGs), we aim to empirically identify the enabling conditions for the sustainable exploitation of Canadian fish stocks. Specifically, we ask: (i) what ecological, social, and

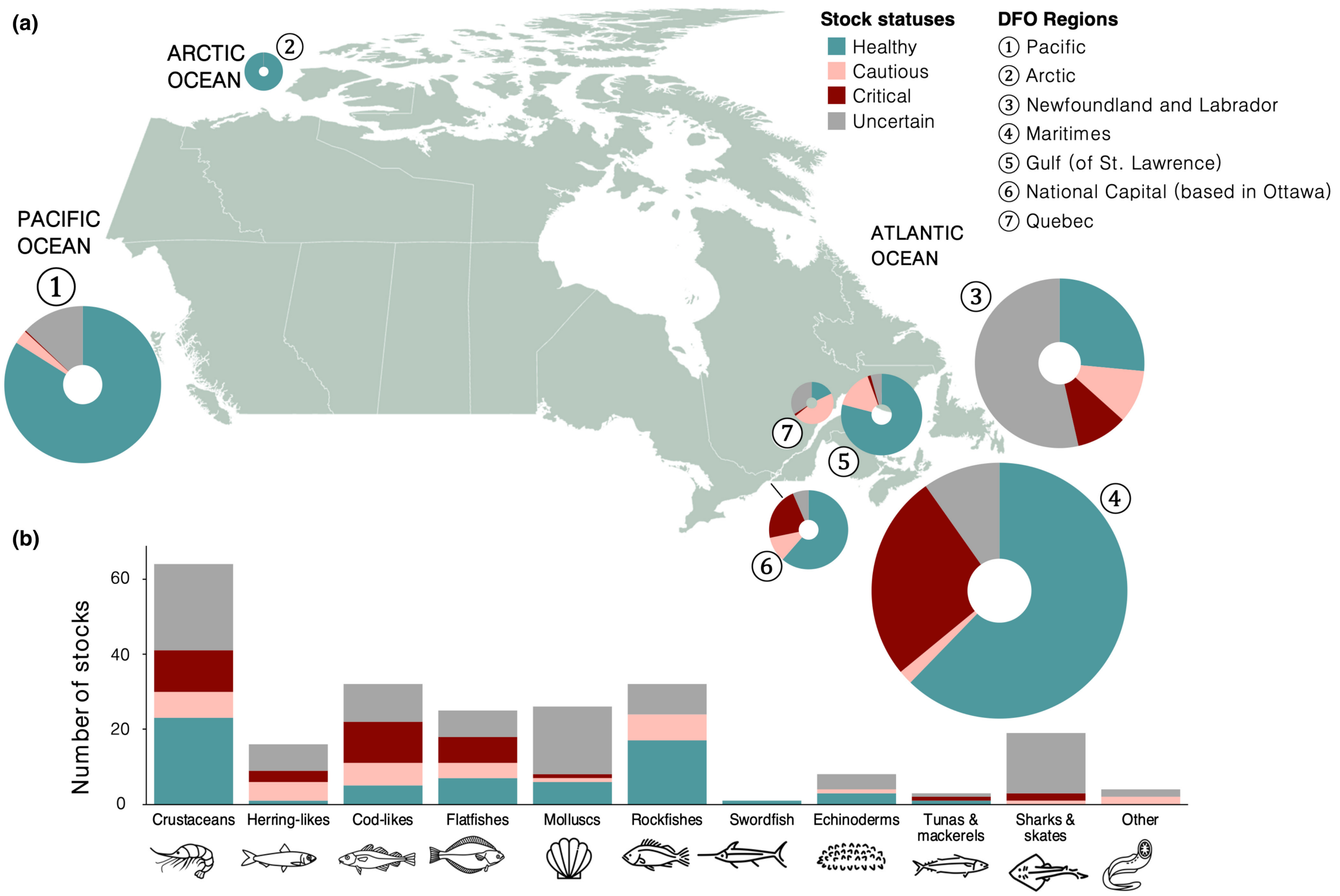

FIGURE 1 Health of fish stocks in Canada. Shown are stock statuses relative to: (a) total catch within each DFO management region, (b) number of stocks by species group; region orb size proportional to total national catch and tonnage (×10^3 mt). Approximately 720,000 mt of marine fish are caught every year in Canada with the largest catches coming from the Maritimes Region (218,000 mt), Newfoundland and Labrador Region (148,000 mt) and Pacific Region (132,000 mt). Note: Most fish stocks are managed by staff at DFO regional offices adjacent to the ocean area where they are fished (i.e., 'DFO Region'), but stocks included in the National Capital Region (NCR) jurisdiction are managed by DFO staff from the department's headquarters in Ottawa (i.e., Canada's capital city and not a maritime area). Data: Schijns and Rangeley (2022); as derived from DFO stock assessment and stock status reports. See Table S1 for biological definitions of stock statuses used in this study.

institutional factors predict healthy stock status and (ii) what lessons can be learned from stocks performing better-than-expected to improve fisheries management for depleted stocks? To answer these questions, we gathered data for 230 fish stocks in Canada and analysed them using a positive deviance approach.

1.2 | Applying a positive deviance framework

Positive deviance analysis originated in epidemiology and nutritional science (Pascale et al., 2010) and is used to identify and learn from individuals, families, or communities who are healthier than expected given their circumstances (often called 'bright spots' or 'positive deviants') in large datasets. This methodology is especially useful for complex applied challenges with interconnected factors – such as those encountered in fisheries management – since it is founded on the premise that unique behaviour and knowledge held by individuals within the system are the basis for deriving proven solutions. Thus far, most positive deviance analyses have focused on addressing human health and international development problems (Marsh et al., 2004), but they have since been extended to large-scale marine conservation challenges (Cinner et al., 2016; Simpfendorfer & Dulvy, 2017). To our knowledge, our application of this approach is the first for a country's commercial fisheries.

While there is no scarcity of literature on effective fisheries management tools (e.g., Selig et al., 2017; Smith et al., 2000), as well as limitations to their successful implementation (Beddington et al., 2007; Cochrane, 1999), a fundamental challenge when discussing the enabling conditions for sustainable fishing can be the inherently different governing regimes among countries. National capacities for collating and analyzing fishery data as well as implementing and enforcing effective and equitable fishing regulations is highly variable across jurisdictions. Within Canada, all marine fishing is subject to the requirements of the *Fisheries Act* and the Sustainable Fisheries Framework (DFO, 2022c), which means all DFO management strategies and decisions are guided by the same

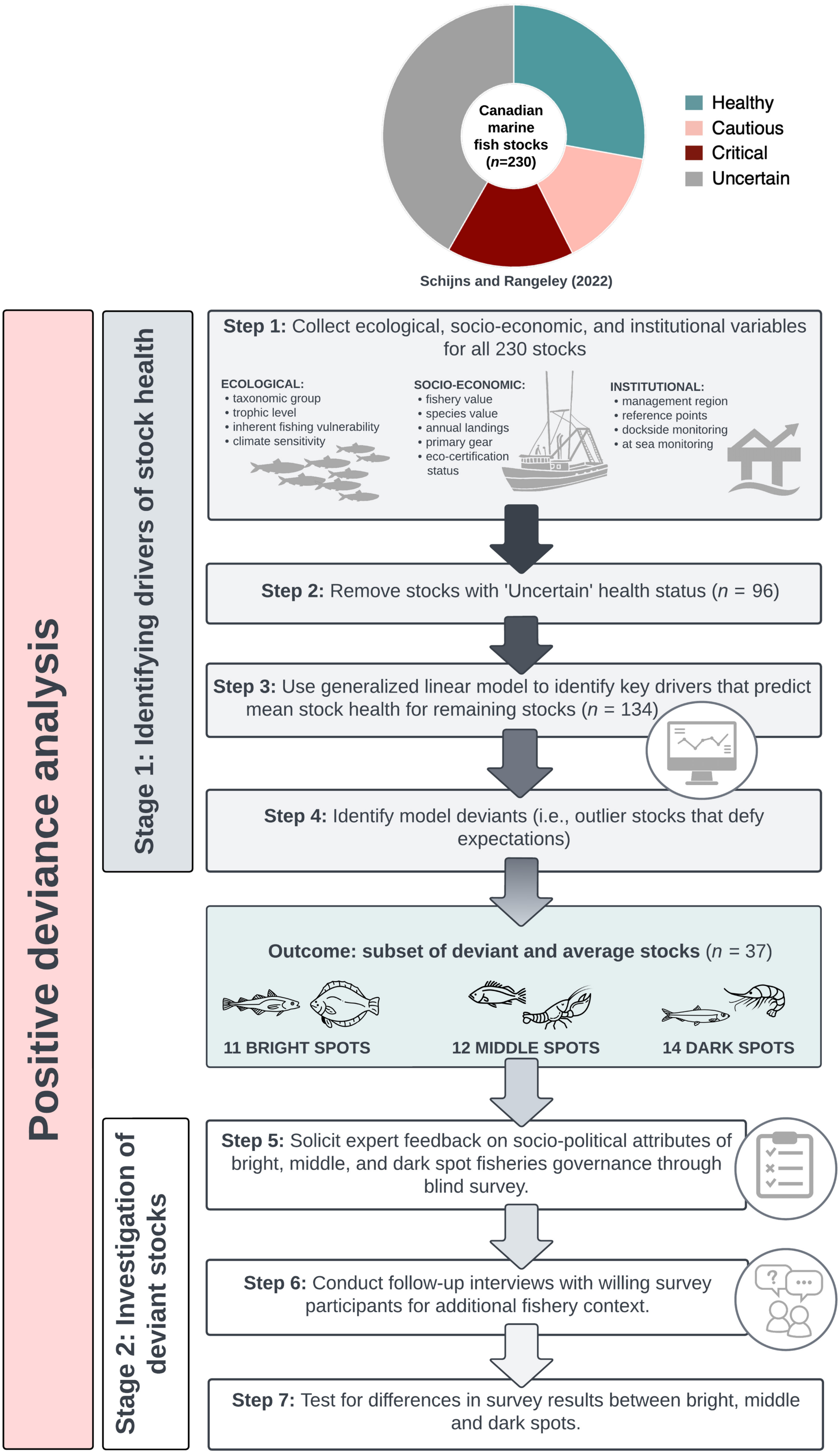
Canadian marine fish stocks (n=230)
Healthy
Cautious
Critical
Uncertain
Schijns and Rangeley (2022)
Positive deviance analysis
Stage 1: Identifying drivers of stock health
Step 1: Collect ecological, socio-economic, and institutional variables for all 230 stocks
ECOLOGICAL:
• taxonomic group
• trophic level
• inherent fishing vulnerability
• climate sensitivity
SOCIO-ECONOMIC:
• fishery value
• species value
• annual landings
• primary gear
• eco-certification status
INSTITUTIONAL:
• management region
• reference points
• dockside monitoring
• at sea monitoring
Step 2: Remove stocks with 'Uncertain' health status (n = 96)
Step 3: Use generalized linear model to identify key drivers that predict mean stock health for remaining stocks (n = 134)
Step 4: Identify model deviants (i.e., outlier stocks that defy expectations)
Outcome: subset of deviant and average stocks (n = 37)
11 BRIGHT SPOTS
12 MIDDLE SPOTS
14 DARK SPOTS
Stage 2: Investigation of deviant stocks
Step 5: Solicit expert feedback on socio-political attributes of bright, middle, and dark spot fisheries governance through blind survey.
Step 6: Conduct follow-up interviews with willing survey participants for additional fishery context.
Step 7: Test for differences in survey results between bright, middle and dark spots.

FIGURE 2 Positive deviance approach with application to Canadian fish stocks. We used a two-stage process to (1) model and identify drivers of fish stock health and (2) investigate 'deviants' (outlier stocks) through expert feedback to better understand enabling conditions for healthy stocks and better-then-expected outcomes. See Table S2 for model variables and sources (Step 1), Table S3 for list of bright, middle, and dark spot stocks (*n*=37), and Tables S4 and S5 for survey (Step 5) and interview (Step 6) respondent demographics. Note: not shown is that the health of removed stocks with 'Uncertain' status (Step 2) were also predicted using the drivers identified by the model (see Section 2 and Supplementary Methods for full methodology and Table S9 for predictions).

laws and policies. Thus, by eliminating the analytical complexity introduced by national differences in governance, we can better compare aspects related to stock health. At the same time, since Canada borders three different oceans – all of which have unique fishing histories and ecosystems – we can still retain a large sample size with diverse target species, fishing fleets, and regional management dynamics.

2 | METHODS

This study features a mixed-methods approach combining quantitative data analyses and qualitative fishery expert surveys and interviews. Our positive deviance analysis was conducted in two stages (described in detail below and depicted in Figure 2). First, we compiled known and quantifiable environmental, economic, and institutional factors to determine the main drivers of stock health in Canada. Using these variables, we then applied a generalized linear model to identify the key drivers of stock status (i.e., predicting the average) and to identify outlier stocks that are performing better ('bright spots') or worse ('dark spots') than expected given the drivers they face. Third, we undertook case-specific investigation of these outliers by soliciting expert feedback from fishers, fisheries scientists, managers, and other knowledge holders. The goal was to identify enabling conditions and existing solutions for the improved management or rebuilding of Canadian fish stocks not currently in the healthy zone. We also used our best performing model to predict the stock status of all 96 stocks with 'Uncertain' status. For this auxiliary analysis, our goal was to provide a more complete picture of fish stock health for Canada that includes all species caught by the country's commercial fisheries.

2.1 | Identifying drivers of stock health

2.1.1 | Data

We used publicly available data from the 2022 Oceana Fishery Audit (Schijns & Rangeley, 2022) as the source for our indicator of fish stock health for 230 marine stocks in Canada. The Fishery Audit classifies all stocks into one of four statuses: 'Healthy', 'Cautious', 'Critical', or 'Uncertain' based on current estimates of abundance (Table S1). These statuses were amalgamated from available DFO publications and thus reflect stock information published in official government documents. The original report and associated data are publicly available and can be downloaded from the Oceana website (www.fisheryaudit.ca). The dataset also includes additional information for the stocks that we used in our analysis (i.e., landings, value, reference points, DFO Region, and at-sea monitoring); see Supplementary Methods and Table S2 for more information on these variables and all others mentioned in Section 2.1.2. Stocks with 'Uncertain' status (*n*=96) were removed for the subsequent part of our analysis, but their health status was later predicted given their variables and the overarching drivers identified by the model (see Section 2.1.2).

2.1.2 | Model

Ordinal multinomial generalized linear models were used to relate stock health status to the set of identified covariates obtained from additional sources: species trophic level, total annual value (log transformed), number of reference points, DFO management region, primary gear type, species inherent vulnerability to fishing, eco-certification status of associated fisheries, and levels of at-sea monitoring for the remaining 135 stocks (Table S2). A full model was fit using all covariates then pruned with Akaike Information Criterion (AIC) based model selection, noting that results and predictions were not appreciably different when using the alternative Bayesian Information Criterion. A measure of predicted climate vulnerability from Boyce et al. (2022) was tested in a separate model with other covariates for a subset of stocks but did not appear correlated with stock health (see Supplementary Methods).

To generate deviants and their uncertainty, we bootstrapped model predictions by randomly sampling the dataset with replacement 10,000 times, refitting the model, and predicting status for each bootstrapped fit. The 'Healthy', 'Cautious', and 'Critical', categories were converted to numeric values – 1, 2, and 3, respectively – allowing us to take means and standard deviations of the bootstrapped deviants. The polr function within the MASS library (Venebles & Ripley, 2002) in R was used to fit the ordered multinomial models and make predictions. All code to perform analysis and visualize results is linked in our Data Availability statement.

We were able to predict the status of the previously removed 'Uncertain' stocks since they had the same covariate information available as other stocks (Table S2) but lacked a health status. These predictions were performed with the best-fitting model structure chosen via AIC as described above. The 'predict' function was used with the MASS package in R to generate predictions using the fitted model.

2.1.3 | Cross-validation of 'health' status

We also re-ran the analysis with a subset of stocks ($n=74$) that had quantitative biomass-based reference points obtained from the RAM Legacy Stock Assessment Database (version 4.495) as a means of verifying whether our results were robust to an alternative measure of stock health. A similar modelling procedure as above was applied to the RAM Legacy data; however, ordinary least squares regression was used due the continuous B/B_{MSY} response variable. We approximated B_{MSY} as half the maximum historical biomass for stocks that did not have an assessment-based B_{MSY} estimate (54%). When comparing these two datasets, we found high overall congruence (Figure S1), which gave us confidence in the robustness and wider applicability of our original, larger dataset.

2.1.4 | Selecting the deviants

To obtain our sample for the positive deviance analysis, the most outlying bright and dark spots were chosen through visual inspection of positive and negative outliers in the model output. We identified roughly the same number of bright and dark spot stocks based on stock deviation from the expected average. Stocks performing as predicted were included as 'middle' spots to represent average outcomes. This resulted in a total of 11 bright, 12 middle spots, and 14 dark spots for further investigation (Table S3).

2.2 | Positive deviance analysis

2.2.1 | Participant consent

As required by the Carleton University Research Ethics Board-A for this study (Project #118966), informed consent from all participants was obtained to access the survey and was again obtained from all interviewees at the outset of each interview. The survey was designed to be anonymous, and participants received no compensation for their involvement in the study. All interviewees were de-identified for analysis purposes.

2.2.2 | Survey distribution

Since the premise for learning from positive deviance analysis relies on identifying unexpected behaviour and/or gaining knowledge from those inside the study system, data collection for the three groups of stocks focused on aspects of fishing and fisheries management not captured through our original model. Therefore, since our research focus was to understand better-than-expected outcomes in Canadian fisheries, the survey was designed to solicit expert feedback only for the 37 stocks identified in Section 2.1.4 as a means of teasing apart differences between bright spots relative to dark and middle spots. To ensure the data obtained from the survey was not biased by stock outcome, a blind survey was used (i.e., respondents were given a list of all 37 stocks, but they did not know if the stock they chose to answer questions for was a bright, dark, or middle spot).

Survey questions focused on the presence or absence of factors related to effective fisheries governance including conflicts over access between different user groups (Charles, 1992; Mitchell et al., 1984; Spijkers et al., 2018), trust between fishers and decision-makers (Fleming et al., 2020; Holm & Soma, 2016; Temby et al., 2015), local resource dependence for food and livelihood security (Aqorau, 2019), environmental non-governmental organization (ENGO) and industry lobbying (Schiller et al., 2021, 2023), and inclusion of different forms of knowledge in decision-making processes (Cvitanovic et al., 2015; Hamelin et al., 2023; Johannes et al., 2008). We additionally explored whether recent environmental changes had affected stock health but might not have been captured at the time of the most recent stock assessment.

The survey was made available online through Qualtrics XM. We distributed the survey to DFO staff by using online government directories for scientists and managers associated with fisheries for the 37 stocks. For fisheries co-managed with an Indigenous government, we contacted the associated Nation's resource management team. To obtain participation from non-governmental organisations, we sent the survey to major Canadian fishing industry associations and environmental NGOs involved in fisheries-related conservation. We relied on a snowball approach and encouraged contacted individuals to share the survey with their networks.

From 120 surveys originally filled out, 42 were sufficiently completed and deemed usable in our analysis. Of these, 30 were completed in full (i.e., every question had a response), while the remaining 12 had enough information to be used for multiple analyses. The lack of responses for some questions is likely because participants were invited to leave a question blank if they preferred not to answer and/or because they chose not to provide additional comments on open-ended questions. A total of 19 surveys pertained to seven different bright spots, 16 were for 11 different dark spots, and seven were for five different middle spots (Table S3). Over 60% of respondents had >20 years of experience with the fishery for which they completed the survey (Table S4). Please see Supporting Information for copy of survey and details on analysis exclusions.

2.2.3 | Interviews

Fourteen survey respondents left contact information for a follow-up interview, and, from this, nine people were still interested in participating when contacted. Although we sought diverse perspectives for this work, we were limited by the individuals who chose to leave their contact information. For this reason, our interviews reflect the perspectives of only DFO employees and fishing industry members (Table S5). All interviews were conducted by LS over Zoom, were audio recorded, and ranged in length from 30 to 45 minutes. Since interviewees filled out the survey for different stocks, the interview was semi-structured based on the interviewee's original survey responses or comments.

2.2.4 | Comparative analysis between bright, dark, and middle spots

All survey questions with presence/absence responses were converted into numerical scores (i.e., 'No' = 0 and 'Yes' = 1); 'Unsure' responses were considered 'n/a' and were not included in the analysis since respondents self-identified as lacking the information. Answers left blank were also not included. In cases where binary information was contradictory across participant responses for the same stock, a '1' was assigned if ≥50% respondents perceived that factor as present. All binary data were tested for significant differences between bright, middle, and dark spots using a Fisher's exact test.

Questions that could be summarized as a count or percentage were analyzed using single-factor ANOVA and Tukey's HSD post-hoc test to test for differences among the three fishery groups. For stocks that received more than one survey response, answers were averaged, and all tests comparing relative percentages were *arcsin* transformed before analysis. Due to the small sample size, interviews were not systematically coded and analysed. However, interviewee information was used to provide context and examples in the discussion as it relates to survey results.

3 | RESULTS

3.1 | Key drivers of fish stock health in Canada

Six of nine tested drivers of stock health were retained after model selection (Figure 3). There was a strong regional effect, with stocks managed by DFO staff in the Pacific, Maritimes, and National Capital Region offices healthier on average than those elsewhere (Figure 3a). Fishing gear also had an effect, where more selective trap and line fishing gears fared better than net gears, on average (Figure 3b). Stocks with no annual catch at present also tended to be healthier than fished stocks (Figure 3b). Although the differences were minor, stocks fished by MSC-certified fishing companies were healthier relative to others (Figure 3c). Counterintuitively, species with higher inherent vulnerability to fishing correlated positively with healthy stock status, as did stocks without target and limit reference points (Figure 3d). Total economic value from the stock (CAD/year) was also positively correlated with stock health (Figure 3d).

When singling out the deviants – stocks that defy expectations – we find that a handful of shrimp (Pandalidae), cod (Gadidae), and herring (Clupeidae) stocks disproportionally dominate both outlier groups regardless of fishing region (Figure 3e; Table S3). We find similar taxonomic concentration for middle spots: three of four Atlantic stocks that fared as predicted were American lobster (*Homarus americanus*, Nephropidae), and all eight middle spots on the Pacific coast were rockfishes (Sebastidae). When looking across DFO management regions, we find that six bright spots came from the Pacific, three from the Maritimes, and one each from the Gulf of St. Lawrence and Newfoundland (Table S3).

3.2 | Investigation of bright, dark, and middle spots

Survey responses show that, on average, dark spot stocks have 3.2 ±0.35 (out of four investigated) sources of fishing mortality to account for, which is higher than middle ($\bar{x} = 2.3 \pm 0.84$ sources) and bright spots ($\bar{x} = 2.1 \pm 0.14$ sources). The proportion of relevant mortality sources accounted for in stock assessments did not significantly differ between the groups, although we found better accounting of mortality in bright spot fisheries ($F_{2,18} = 2.624$, $p = .099$; Figure 4a). The relative inclusion of non-governmental knowledge sources (i.e., from commercial fishers, coastal communities, and Indigenous communities) in stock assessments also did not significantly differ across tested fisheries ($F_{2,16} = 0.676$, $p = .52$; Figure 4b). The only stock perceived as lacking a systematic process for the inclusion of any non-governmental information was Georgia Strait East sidestripe shrimp (Pandalopsis dispar, Pandalidae; dark spot). Overall, interviewee scores for trust were highly variable, but perceived trust between DFO managers and fishers was highest in middle spot fisheries ($\bar{x} = 6.0 \pm 2.8$ out of 10) followed by bright spots ($\bar{x} = 5.2 \pm 2.8$) and dark spots ($\bar{x} = 4.2 \pm 2.8$) but there was no significant difference between the groups ($F_{2,16} = 0.733$, $p = .50$; Figure 4c).

The average number of external influences perceived to be affecting management decisions for bright spot fisheries was lower ($\bar{x} = 0.84 \pm 0.83$ influences) compared to middle ($\bar{x} = 2.8 \pm 1.6$ influences) and dark spots ($\bar{x} = 1.5 \pm 1.2$ influences), but these differences were also not significant ($F_{2,17} = 3.341$, $p = .060$; Figure 4d). When comparing the relative influence of different stakeholders and rightsholders across the three groups, we found that management decisions for seven of 11 dark spots (64%) had been influenced by fishers and/or fisher associations in recent years, compared to only one of five bright spots (3LNO yellowtail flounder; Limanda ferruginea, Pleuronectidae) and three of five middle spots, but our Fisher's Exact test found no significant difference between the three groups ($p = .38$). The presence of perceived ENGO influence was significantly different across groups ($p = .032$) yet perceived presence of Indigenous rightsholders ($p = .84$) and academics were not ($p = .49$). When looking at average presence in the representation of these different groups, we find notable differences between them, with more balanced participation in bright spot fisheries, and a greater perceived industry influence on decision-making in middle and dark spot fisheries (Figure 4e).

Illegal and unregulated fishing was identified as a concern in four dark spots, two middle spots, and one bright spot, but these differences were not statistically significant (Figure 4f). Perceived conflict between different fishery users was present in one of five bright spots (Outside yelloweye rockfish; Sebastes ruberrimus, Scorpaenidae) compared to all five middle spots six of ten dark spots, resulting in a significant difference between

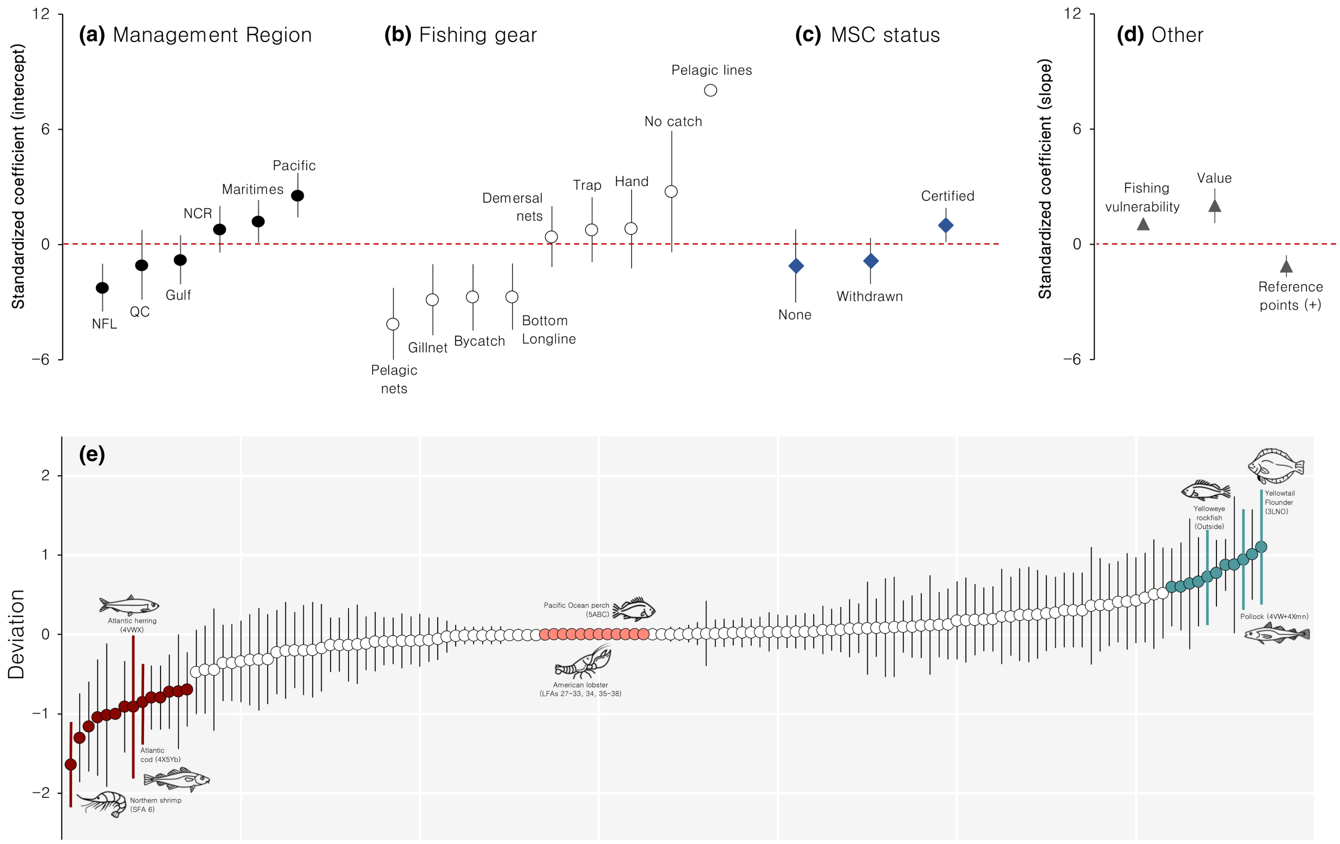

FIGURE 3 Predicting mean stock health and deviants. (a–d) Significant predictors of fisheries health in Canada. Shown are mean coefficients from the best-performing model, with 95% confidence intervals; (e) the bootstrapped deviation of Canadian stock health relative to the mean, as predicted by our best performing model. Positive deviants (teal), middle spots that perform as predicted (pink) and negative outliers (burgundy) are highlighted with some example stocks shown. Error bars are 95% CI; please refer to Table S6 for full list of model predictions and Table S10 for full list of gears included in the gear groups in Panel b. MSC, Marine Stewardship Council; Management Region Abbreviations: NFL, Newfoundland and Labrador; QC, Quebec; NCR, National Capital Region.

the three groups ($p=.042$; Figure 4g). The same number of fisheries (six) were identified by survey respondents as having conflicts related to Indigenous and non-Indigenous fisher access as for conflict related to inshore and offshore fleet disputes. One stock, SFA 4 Northern shrimp (dark spot), was identified as suffering from both challenges and, across all stocks, 4XVW herring (dark spot) had the most different sources of conflict (Table S7). External to access disputes within the fishing community, conflict between ENGOs and industry members was identified for two Pacific Region stocks (one middle and one bright), in part due to a perceived lack of process and stakeholder engagement related to proposed marine protected areas (MPAs) (Table S7). There were no other statistically significant differences when comparing the perceived economic and cultural value of bright, dark, and middle spot fisheries (Figure 4h,i).

While recent changes in environmental conditions are perceived to be impacting catches for over three-quarters of stocks in this analysis, there was no significant difference when comparing between the groups (Figure 4j). Of the shifts observed, changing water temperature was the most commonly identified (i.e., affecting 77% of the stocks perceived to be affected by a changing environment), followed by changes in seasons and weather patterns (62%), changes in predation pressure (54%) and changes in food availability (15%); two dark spot stocks were perceived to be impacted by all four of these conditions (Table S8).

3.3 | Predicting 'uncertain' stock status

The 96 stocks with 'Uncertain' status account for roughly one-fifth of all landings in Canada (Figure 1a). Using our best model (see Section 2.1.2) to predict their health status from the same covariates as other stocks, we found 38 stocks were predicted to be in the healthy zone, with a further 24 in the cautious zone, and 34 in the critical zone (Table S9). When 'Uncertain' predictions are combined with the stocks of known status, the proportion of Canadian stocks in the critical zone is estimated at 30.4%, the proportion in the cautious zone is 25.2%, and the proportion in the healthy zone is 44.3%. Based on the landed volume, these predictions also suggest that upward of 70% of the total annual catch (mt) of Canadian seafood could be coming from healthy stocks ($B > 0.8B_{MSY}$).

Given the importance of DFO Region as a key driver in our model, and because Newfoundland and Labrador had the most 'Uncertain' stocks initially ($n=34$), we find that 68% of all stocks predicted to

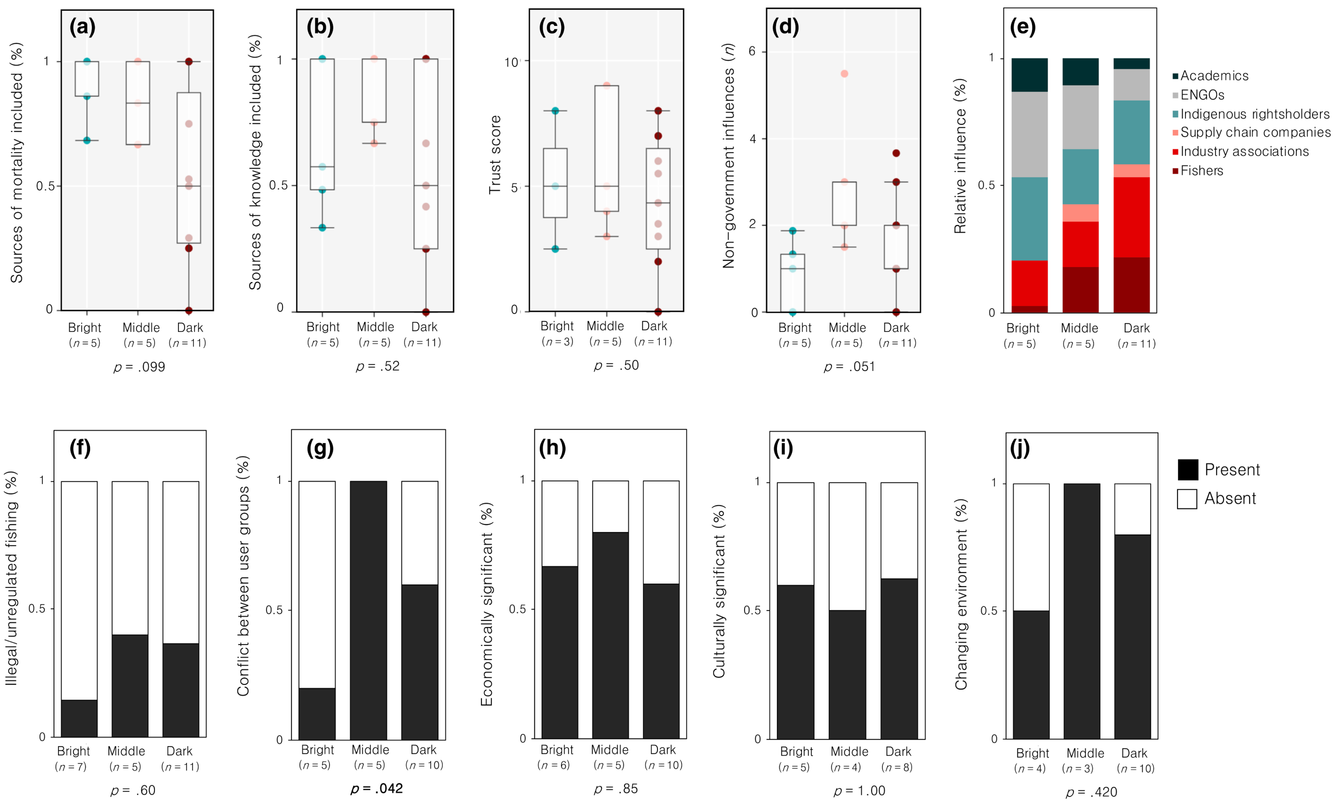

FIGURE 4 Socio-economic and environmental differences across bright, dark, and middle spot fisheries. (a and b) Information included in fishery stock assessments; (c–e) Relationship between DFO and fishery stakeholders/rightsholders in decision-making processes; (f and g) Relationship between fishers; (h and i) Local value of fishery; (j) Ecosystem conditions within the last five years. (Note: a–d depict median ±1.5 IQR, *n* refers to the number of fisheries analyzed in each category, not the number of survey responses.) ENGO, Environmental non-governmental organization.

be critical are from this region. In contrast, seven of nine 'Uncertain' stocks in the Maritimes Region were predicted to be healthy. For taxonomic groups, we find that six of seven stocks of herring-like fishes (i.e., Osmeridae and Clupidae) were predicted to be in critical condition. The 'Uncertain' stocks of hagfish (Myxinidae; $n=2$) and tuna (Scombridae; $n=1$) were all predicted to be in the healthy zone and over half of 'Uncertain' crustacean ($n=23$) and elasmobranch ($n=16$) stocks, respectively, were also predicted to be healthy.

4 | DISCUSSION

Here we adapted a positive deviance approach to better understand ecological, socio-economic, and institutional drivers of fish stock health in Canada. By focusing on outliers that are performing better (or worse) than expected by their circumstances, we were able to derive some of the enabling conditions for successful management of exploited stocks in this country. The approach demonstrated here could be easily replicated for fisheries elsewhere and may help inform key requirements and processes for effective management interventions to overcome prevailing challenges.

As identified by our modelling approach, major drivers of stock health specific to Canada included differences in management region, fishing gear, eco-certification, and landed value. Species' inherent fishing vulnerability and the presence of management reference points had additional effects. Our expert survey further highlighted that balanced stakeholder influence in decision-making, low conflict over access within the fishery, and proper accounting of all mortality sources lead to better-than-expected outcomes. Detailed interviews further supported the importance of routine and standardized data collection (in conjunction with regular stock assessments) as well as effective catch monitoring. As we discuss in detail below, we find that the Canadian government does have the capacity to implement science-based management measures and state-of-the-art monitoring programs, especially when industry members lend logistical and financial support. At the same time, the people involved matter, and we discuss how nuances in the relationships between stakeholders and policymakers can affect regional fisheries governance, driving both positive and negative outcomes.

4.1 | The necessity of reliable data

Although a greater proportion of healthy stocks have both upper and limit reference points (86%) relative to cautious (63%) or critical ones (67%), the effect of reference points in our model

TABLE 1 Observations and perceptions of interviewees from positive deviance survey.

Context	Quote (#)	Stock	Quote	Source
The necessity of reliable data	1	*4X snow crab* (*dark spot*)	'We have relatively frequent reports about lobster fishers that are retaining snow crab [and] using it as bait in their traps'	Interviewee [DFO-2]
	2	*4X5Yb Atlantic cod* (*dark spot*)	'4X5Yb cod is caught incidentally in lobster trap fisheries, however mortality estimates are not yet available and therefore cannot be incorporated into [the] stock assessment'	Interviewee [DFO-1]
	3	*4X5Yb Atlantic cod* (*dark spot*)	'There is some illegal discarding of cod in the mixed groundfish fishery'	Survey respondent [DFO manager]
	4	*4VWX Atlantic herring* (*dark spot*)	'Up until more recent years, there was very little monitoring about [bait fishing]. We had potentially huge numbers of bait licenses out there with daily limits in place…[but] we weren't really monitoring that well so there's a potentially huge scope for additional unaccounted for mortality there'	Interviewee [DFO-4]
	5	All rockfishes and Pacific Ocean perch (as part of the Pacific Region groundfish fishery; bright and middle spots)	'Once [the catch is] offloaded, they check our numbers in our electronic logbooks… if those numbers don't match up, then [the recorded footage from our trip] is automatically audited. And if we're found to have broken any of the rules in place, then we're punished'	Interviewee [Industry-1]
	6	All rockfishes and Pacific Ocean perch (as part of the Pacific Region groundfish fishery; bright and middle spots)	Total annual monitoring costs for all the BC commercial groundfish hook & line and trap fisheries (halibut, sablefish, rockfish, lingcod, dogfish) is about $1.425 million (hails, logbooks, at-sea [electronic monitoring] systems, dockside validation, halibut tagging, program and data management)…Industry is responsible for the full cost of the delivery of the comprehensive catch monitoring program	Survey respondent [Industry association representative]
	7	Georgia Strait East sidestripe shrimp (dark spot)	'DFO only goes out and does a handful of 20-minute tows every two years and it has failed that obligation many times lately'	Survey respondent [Fisher]
	8	Georgia Strait East pink and sidestripe shrimp (dark spot)	'We had a petition to do [a survey] a while ago, but it also didn't pass. [DFO has] a policy that if the areas don't get surveyed, they'll [set the quota] at the lowest [catch] of the last three years…And if [the fishery] hasn't been opened, then the lowest is 'zero"	Interviewee [Industry-2]
Collaboration or conflict: Industry influence on management	9	n/a	'I'm not talking about specific people. I trust the [DFO staff] I know. I'm talking about DFO as an organization …When it comes to [federal] policies that are put in place, that's where there's a lot of mistrust [since] it directly affects those of us here on the ground [but] we don't have a lot of voice in Ottawa' (i.e., Canada's capital)	Interviewee [Industry-1]
	10	SFA 4 Northern shrimp (dark spot)	'one of the main fisheries-related economic drivers in the region'	Survey respondent [Fisher]
	11	SFA 6 Northern shrimp (dark spot)	'has supported hundreds of harvesters and 4 shrimp plants in the region [and] led to international containerized shipping and a multi-million-dollar cold storage facility built in St. Anthony'	Survey respondent [Special Allocation Holder]
	12	4VWX Atlantic herring (dark spot)	'about 2000 people are employed from this stock'	Survey respondent [DFO scientist]
	13	4VWX Atlantic herring (dark spot)	'all of the potential management procedures—at least for the simulation environment—that get you out of the 'Critical' zone over 15 years require substantial curtailing of fishing [and] we were told informally that these outcomes wouldn't be viable [because] they wouldn't have enough product to retain operations'	Interviewee [DFO-4]

TABLE 1 (Continued)

Context	Quote (#)	Stock	Quote	Source
	14	Yelloweye rockfish (bright spot)	'we don't have to agree with [the stock assessment], but we have to go along with it until it's proved better…if the science says we need to react to something [then] we need to react to it'	Interviewee [Industry-1]
	15	Yelloweye rockfish (bright spot)	'because halibut is so valuable, it's the main [species] that is limited by a yelloweye quota… [the halibut hook-and-line fleet is] not directed on yelloweye, but they have the biggest stake in making sure that there's enough quota so that [the fishery for] halibut doesn't get closed… a lot of the work that we do in monitoring yelloweye is actually in conjunction with so the Halibut Management Association'	Interviewee [DFO-3]
Fishery conflicts can be overcome with strong leadership, good communication, and time	16	Yelloweye rockfish (bright spot)	'[Food, Social and Ceremonial] fishing is a pretty unknown quantity in our stock assessments. We don't have good data on FSC. But [rockfish] are certainly very important and prized food source in First Nations communities…The other thing that's come on recently is court decisions that have established that the Nuu-chah-nulth [Nation] on the westcoast of Vancouver Island have a commercial constitutional right to fish as well. And so how that gets managed is something our managers have been really challenged by because they have been required to give quota for halibut and yelloweye. And [those species] are certainly caught in conjunction [which as] led to really high bycatch rates of yelloweye'	Interviewee [DFO-3]
	17	All rockfishes and Pacific Ocean perch (as part of the Pacific Region groundfish fishery; bright and middle spots)	'We used to have gear wars all the time. They'd set on top of each other because everybody's racing to catch fish …But we don't see that very often anymore. There is still conflict because trawl catches halibut as a bycatch…[but] closing important halibut spots—like the 800-line or the circle spot—trawlers have agreed to stay out of those spots just to co-exist. Those kinds of discussions are happening more now [and] the role the government needs to play is to facilitate those discussions [between fleets] to set clear objectives …Generally, the best thing for [DFO] to say is 'we want you to come to an agreement on how to work it out. Because if you leave it to the government to figure out, we'll make everybody unhappy'. So, in that way, they provide the resources'	Interviewee [Industry-3]
	18	All rockfishes and Pacific Ocean perch (as part of the Pacific Region groundfish fishery; bright and middle spots)	'[the trawl industry] had this shared purpose because of the IQ [framework]… Under the old system it was: 'Let [market access] be everyone else's problem, I'll just go out and fish'. But now everybody shares in the same incentive, so those kinds of programs also help'	Interviewee [Industry-3]
Mitigating bycatch and incentivizing collaboration through market incentives	19	Yelloweye rockfish (bright spot)	'with yelloweye having COSEWIC designation as 'Threatened' and SARA status of 'Special Concern', [the halibut fleet] have to be really careful with that, otherwise that could really damage their MSC certification. That's certainly another incentive for them to put a lot of effort into making sure that the stock is rebuilt and it's not constraining them'[a]	Interviewee [DFO-3]

Note: Feedback from all interviewees was used to contextualize results from the survey; 'DFO' includes both government scientists and managers and 'Industry' includes both fishers and fishing association representatives. No quotes are provided in the manuscript for one interviewee (Industry-5) as this individual did not consent to their inclusion. Survey respondent affiliation given based on how the participant self-identified.

[a]COSEWIC (the Committee on the Status of Endangered Wildlife in Canada) is an independent scientific committee designated with the responsibility of identifying species at risk of extinction in Canada and assessing their conservation status. The Canadian Government considers COSEWIC designations when choosing whether or not to officially list a species under SARA (the *Species At Risk Act*).

is negative after fishing gear and DFO Region are accounted for (Figure 3d). This points to the fact that many stocks are not in the healthy zone (i.e., B $\geq 0.8B_{MSY}$) despite having reference points, possibly due to the lack of an associated harvest strategy and/or a lack of its implementation (Archibald et al., 2021a), or other factors impeding recovery. For example, we found differences in both the number of mortality sources to account for in dark spot stocks relative to bright spots, and the degree to which these sources were included in stock assessments (Figure 4a). This outcome exemplifies a key data challenge facing the effective management of many fisheries worldwide (Pauly & Zeller, 2016) since incomplete estimates of total removals can lead to biased assessments and inaccurate projections of sustainable yield. In particular, unknown quantities of bycatch of 4X5Yb Atlantic cod and 4X snow crab (Chionoecetes opilio, Oregoniidae) were highlighted as a concern for these dark spots (Table 1; Quotes 1–3), which suggests mortality of these species incurred by other commercial fisheries is not fully accounted for in stock assessments.

Although at-sea monitoring was not identified as a driver of stock status by our model, surveyed experts emphasized the importance of catch verification for ensuring mortality estimates are accurate. For example, in the case of dark spot 4VWX Atlantic herring (Clupea harengus, Clupeidae), one interviewee mentioned how efforts to improve dockside observer coverage were improving but, until recently, there was limited observational data regarding its use for bait (Table 1; Quote 4). By comparison, monitoring in the Pacific Region's groundfish trawl fishery (which targets middle spot Pacific Ocean perch; Sebastes alutus, Scorpaenidae) and the Pacific halibut (Hippoglossus stenolepis, Pleuronectidae) hook-and-line fishery (which has bycatch of bright spot yelloweye rockfish) was described by Interviewee DFO-3 as 'stringent', with all vessels currently subject to 100% observer coverage and dockside catch verification (Table 1, Quote 5). Notably, industry covers all costs associated with observer programs in these fleets which, since 2006, have been transitioning to using electronic (e-) monitoring systems. Even for one fleet, current e-monitoring costs are substantial (Table 1, Quote 6). Beyond their value for data verification, Interviewee DFO-3 also highlighted that using e-monitoring programs would eliminate fishery observer harassment and assault, which are pervasive problems in Canadian fisheries (Thompson, 2021, 2022).

The variation in monitoring effort across fleets identified here is consistent with reports by The Auditor General of Canada in 1999 and 2016, both of which highlighted inconsistencies in levels of coverage and reliability of DFO's observer programs (OAG, 2016). Further, while DFO finalized a new Fishery Monitoring Policy in 2019 with a framework for providing consistent, timely, and accessible data, the Auditor General recently reported that the department has not yet met the monitoring requirements set out by its own policy for any of the 156 stocks prioritized for application (OAG, 2023). While OAG (2023) does not specify which stocks were prioritized or evaluated, this outcome suggests that the robust e-monitoring system in Pacific groundfish discussed above is indeed a positive outlier, and could potentially serve as a model case to improve other fisheries. We also found that in addition to fishery-dependent data, respondents raised concerns over how some fishery-independent data are collected and used by DFO in the case of two dark spots, Georgia Strait East pink (Pandalus borealis and P. jordani, Pandalidae) and sidestripe shrimp (Table 1, Quote 7–8). Again, these results are consistent with OAG (2016), which found that DFO was not conducting all scientific surveys it had planned for certain fisheries and, therefore, the department could not properly classify the health status of the associated stock. If fishers perceive economic uncertainty due to data collection shortcomings, it can lead to a breakdown in communication and trust between managers and industry. This may partly explain why these two dark spots had the lowest trust score between fishers and DFO in our study (i.e., 0/10).

In addition to shortcomings in catch monitoring and mortality data, DFO currently lacks sufficient abundance data to determine the health status of 42% of Canadian fish stocks (see Introduction). Hence we used our best-fitting model to predict the status for these 'Uncertain' stocks (Section 3.3, Table S9). A similar effort by Schijns (2022) using an unrelated methodology yielded comparable results overall (i.e., 41% Healthy, 29% Cautious, 25% Critical), but with noticeable differences for individual stocks, relative to our predictions. This disparity may be due to differences in datasets (2021 vs. 2022 Fishery Audit data) and methodology, since the model parameters used by Schijns (2022) are based predominantly on species life history. We suggest additional investigation into data-limited approaches for predicting stock health, but caution that such efforts should not be viewed as a replacement for systematic data collection and regular stock assessment for all Canadian fish stocks.

Obtaining solid baselines of abundance and fishing mortality will be especially vital as Canadian fishing communities adapt to the impacts of climate change. Although climate sensitivity was not retained as a key driver of stock status in our model, survey responses suggest that catches associated with many stocks – especially dark spots – are changing in response to environmental conditions (Table S8). In particular, the northwest Atlantic is predicted to be among the fastest warming regions globally and, in combination with insufficient management responses, sea surface temperature changes have already been linked to the collapse of U.S. Atlantic cod stocks adjacent to the Canadian border (Pershing et al., 2015). DFO management documents recognize uncertainty around how climate change will affect Canadian stocks (Boyce et al., 2021). Yet there are few safeguards in place to account for this uncertainty and ensure future productivity of stocks (Pepin et al., 2022), while maintaining ecosystem-level resilience as environmental changes intensify (Frid et al., 2023).

4.2 | Collaboration or conflict: industry influence on management

We found significant differences in stock health among DFO Regions (Figure 3a), which could be due to both environmental and institutional factors. For example, the Pacific coast of Canada (top regional predictor of 'Healthy' stocks), has higher primary productivity compared to the Atlantic, a difference that would positively influence biomass, resilience, and recovery. Further, each DFO Region has a unique exploitation history, with some groundfish stocks in the Newfoundland Region (lowest predictor of healthy stocks) subject to industrial-scale fishing pressure for decades to centuries longer than most Pacific stocks. Stocks subject to prolonged, intense overfishing have slower and less predictable recovery times, independent of life history traits (Neubauer et al., 2013).

Under this broader umbrella of beneficial conditions for the Pacific, it remains that the exploitation of marine life in Canada is fundamentally linked to how DFO is structured, which also includes the balance of power in relationships between managers and industry members, both currently and historically. Although DFO is a federal department, their offices (and staff) are organized regionally. Over time, this has resulted in a siloed institutional structure with limited communication and coordination between employees from different regions (Soomai, 2017). This disconnect may partly explain the trust scores assigned by some industry members (Table 1, Quote 9).

Although industry members and other non-governmental actors are perceived to be influencing the management of all stocks in our study (Figure 4d), survey and interview results suggested there are differences between how fishers and industry associations engage in bright vs. dark spot fisheries, and how external stakeholder opinions are balanced with scientific assessments. Most interviewees suggested that industry engagement is critical for a variety of management-related activities, including obtaining accurate catch and effort data through onboard monitoring programs, assisting with stock assessment surveys, providing information on potential no-take areas, and/or ensuring management measures are consistent with real-world fishing conditions. This kind of collaboration and associated participatory decision-making with resource users – and their shared responsibility for ensuring stock health – are in keeping with the aspirations of Canada's Sustainable Fishery Framework (Stephenson et al., 2019), the revised Fisheries Act (Hamelin et al., 2023) and observations on industry participation in some of world's smallest (Johannes et al., 2008) and largest (Schiller et al., 2023) fisheries. Importantly, however, this type of industry involvement should not be confused with industry interference (i.e., regulatory capture), which has been highlighted as a concern in Canadian fisheries and aquaculture for decades (Godwin et al., 2023).

We found that, on average, dark spot fisheries have the highest relative influence of industry on decisions in recent years (Figure 4e). When asked how industry input is weighed relative to DFO's scientific advice for stocks in the Maritimes Region, Interviewee DFO-1 reiterated a long-standing challenge facing fisheries management in Canada, 'the science has a heavy weight usually but it's certainly not the only consideration because DFO has a dual mandate: it's to conserve stocks but also keep fishermen in jobs'. Noticeably, substantial economic investments and local employment were consistently highlighted by survey respondents in the context of two dark spot shrimp stocks, both of which support large commercial fisheries and regional processing facilities (Table 1, Quotes 10–11). In addition to highlighting concerns over the economic implications of reducing quotas, Newfoundland-based industry associations have publicly criticized DFO's stock assessment model and reference points for the SFA 6 stock (FFAW, 2019) and assessments of at least three other Atlantic Ocean stocks currently in the critical zone (Anonymous, 2023; Moore, 2023; Withers, 2019). These interactions reflect a broader regional political landscape, where a highly antagonistic relationship between the federal government, the provincial government, and members of the fishing industry (Bailey, 2015; Chase, 2003) is tied to repercussions of economic insecurity brought on by the cod collapse and associated moratorium three decades ago (Thornhill-Verma, 2021).

At the same time, concerns over livelihood impacts were also highlighted in our survey for the 4VWX Atlantic herring stock (Table 1, Quote 12), which accounts for over 25% of the Maritimes Region's commercial seafood landings. In 2022, members of the herring industry independently proposed their own harvest strategy (The Bay of Fundy Herring Industry, 2022) after being critical of the peer-reviewed model used by DFO scientists and associated pathways for rebuilding (Table 1, Quote 13). Recent research shows that 4VWX herring is one of only three Atlantic stocks (and the only one in the critical zone) with more industry representatives attending stock assessment meetings than DFO employees (Hamelin et al., 2023). This example is similar to observations from the Newfoundland and Labrador Region, where results of a recent survey conducted by one of Canada's largest labour unions found that one-third of DFO employees there have seen or experienced interference by industry lobbyists regarding science-based work in the last three years and that 'actions taken by the Department [of Fisheries and Oceans] have exhibited a pattern where this type of interference with scientific work is commonplace' (O'Brien, 2022).

Despite these examples, conflict between DFO employees and industry is not universal and does not always lead to an impasse. For example, in 2021, the Fisheries Minister implemented a scientifically advised 10% reduction in the exploitation rate of Strait of Georgia Pacific herring (bright spot) (DFO, 2021b), despite a highly charged political atmosphere carried over from the previous year's decision (Stanfield, 2020). Also in the Pacific Region, four interviewees familiar with groundfish fisheries (which catch middle/bright spot rockfishes and middle spot Pacific Ocean perch) noted a predominantly respectful and collaborative relationship between government employees and industry, even under challenging circumstances (Table 1, Quote 14). For example, in 2016, the halibut hook-and-line fleet worked with DFO to address concerns over yelloweye rockfish (bright spot) bycatch – and an associated 60% quota reduction for this species – by changing their spatial footprint to avoid areas with traditionally high yelloweye encounter rates (Forrest et al., 2020). In this case, 'fishermen were definitely listened to and drove the solution…it was a very positive process for everybody involved' [Interviewee Industry-1]. Additional context for this solutions-focused outlook for yelloweye was provided by one survey respondent who wrote, 'the entire commercial fishing industry on Canada's Pacific coast is dependent on [the yelloweye] stock' since it is a "choke" species' (Table 1, Quote 15; Boyes, 2018). Importantly, tensions between DFO and fishers may arise especially where economically valuable stocks have been depleted and in the critical zone rather than during times when those fisheries are productive.

Lastly, we highlight that the only bright spot in the Newfoundland Region – 3LNO yellowtail flounder – is a transboundary stock managed not by DFO but by the Northwest Atlantic Fisheries Organization (NAFO) since 1977. Although Canada is currently allocated ~40% of the total annual quota for this stock, NAFO is responsible for conducting the stock assessment and NAFO member states representatives agree on annual catch limits (which included a moratorium on fishing from 1994 to 1997 due to concerns of overfishing). Since the fishery was re-opened, annual quotas have been at or below those recommended by NAFO's science advisory team. This stock has had reference points for two decades and, in 2012, DFO developed a harvest strategy for 3LNO flounder within the Canadian EEZ (DFO, 2021a). These management efforts are likely aided by the fact that only one company (Ocean Choice International) fishes this stock in Canadian waters, and they also voluntarily refrain from fishing during spawning season for product quality reasons (Atkinson et al., 2010).

4.3 | Fishery conflicts can be overcome with strong leadership, good communication, and time

Meaningful and equitable co-management of fisheries between the Canadian government and Indigenous communities has been slow and sporadic (Swerdfager & Armitage, 2023) and navigating federal Reconciliation commitments is challenging, even in bright spot fisheries (Table 1, Quote 16). Survey results show significantly higher levels of conflict between Indigenous and non-Indigenous fishers in dark and middle spot fisheries, which is consistent with recent incidents of racism and violence in some Atlantic lobster fisheries (middle spots) over resource access (Grant, 2021). Similarly, survey respondents identified conflict between Indigenous and non-Indigenous fishers in SFA 4, a fishing area that borders Nunatsiavut (a territory in Labrador governed by Inuit). The SFA 4 shrimp fishery has a poorly defined allocation process where annual quotas are distributed at the discretion of the Fisheries Minister (Kourantidou et al., 2021). Power imbalances carried forward from Canada's colonial origins play a substantial role in current conflicts in these crustacean fisheries (Foley et al., 2017; Gaudet, 2022), and both situations are likely further compounded by the fact that Atlantic lobster is by far the Maritimes Region's most valuable seafood export (DFO, 2022a) and northern shrimp is perceived as the most valuable species in Nunatsiavut (Foley et al., 2017).

While it is beyond the scope of this paper to debate the benefits and shortcomings of individual transferable quotas (ITQs) as a fisheries management approach (Branch, 2009; Chu, 2009), feedback from interviewees is consistent with research showing how this allocation framework provided the right incentives for different Pacific coast fleets to work collaboratively (Davis, 2008; Koolman et al., 2007), especially in the context of addressing monitoring and bycatch challenges (Edinger & Baek, 2015; Stanley et al., 2015). In this regard, Interviewee Industry-3 suggested that at least one-fifth of individuals still involved in the ITQ process today were there at the outset of the process over three decades ago. Based on the perceived outcomes of success associated with the ITQ allocation framework and a solid history of overcoming disputes over time, this individual also explained that emerging conflicts between the main gears (e.g., trawl and hook-and-line) can now often be addressed at the fleet level, with DFO serving a facilitation role (Table 1, Quote 17). These observations are consistent with the finding that social capital and local leadership are important factors for effective fisheries co-management (Gutierrez et al., 2011).

Beyond a defined allocation system, incentives provided by the market have also helped reduce conflict and improve relationships between stakeholders in the Pacific Region. For example, Interviewees Industry-4 and Industry-5 discussed how protection of a sensitive area of deepwater sponges and corals off the coast of B.C. in 2015 was largely driven by the groundfish trawl fleet's desire to obtain a 'Best Choice' (Green) rating from Seafood Watch, the Monterey Bay Aquarium's sustainable seafood recommendation program. This incentive led to the BC Groundfish Habitat Conservation agreement, a three-year collaboration between multiple environmental NGOs and industry members and resulted in a trawl fishery area closure, the world's first habitat-specific fishery quota, and the desired Seafood Watch rating (Wallace et al., 2015). Importantly, a strong pre-requisite to this type of collaboration was existing stability and cooperation within fleets (Table 1, Quote 18).

4.4 | Mitigating bycatch and incentivizing collaboration through eco-certification incentives

Results from our analysis show a slight positive relationship between Marine Stewardship Council (MSC) eco-certification and target species stock health (Figure 3d). For Canadian fisheries writ large, MSC certification may provide benefits when it comes to timely science: the average stock assessment age for stocks in our analysis without MSC-certified fisheries was more than double that of those with MSC-certified fisheries (i.e., 6.7 $\pm$4.2 years vs. 3.1 $\pm$2.4 years old). Market recognition goals are even highlighted in the most recent DFO management plan for 3LNO yellowtail, which states that the push for MSC certification 'resulted in an increased focus on the development of [Precautionary Approach]-compliant frameworks, including the establishment of reference points and harvest control rules…resulting in an increased demand for management and scientific capacity and capabilities' (DFO, 2021a). This example highlights certain benefits related to MSC certification, but also speaks to capacity limitations at DFO, potentially regarding the MSC assessment timeframe. Indeed, this challenge is in keeping with concerns raised in 2017, where researchers found that 60% of Canadian fisheries with MSC certification still had open conditions (i.e., required improvements for re-certification) related to harvest control rules and/or reference points (Arnold & Fuller, 2017). Today, such open conditions remain for MSC-certified fisheries targeting the dark spot stocks of SFA 4 and SFA 6 shrimp (Addison et al., 2022).

In addition to the push for harvest strategies, eco-certification incentives may also have helped incentivize regular data collection and monitoring for bycatch species. For example, efforts to keep Atlantic cod and witch flounder (3NO stocks) bycatch to 1% of total landings were also met by the MSC-certified fishery for 3LNO yellowtail flounder (bright spot) through the implementation of a real-time bycatch monitoring system and 'move on' procedure (Blyth-Skyrme & Atkinson, 2014). Similarly, Interviewees Industry-5 and DFO-3 highlighted monitoring and bycatch mitigation efforts related to yelloweye rockfish (bright spot) were largely tied to the MSC-certification of hake and halibut fisheries on the Pacific coast (Table 1, Quote 19). Since yelloweye rockfish is listed on the Canadian Species At Risk Act (SARA), it is considered an 'Endangered, Threatened or Protected' (ETP) species under the MSC assessment framework and therefore requires additional controls within the target fishery (DeAlteris & Trumble, 2019). Comparatively, two dark spots (canary rockfish and Pacific cod), are also caught as bycatch in the MSC-certified Pacific halibut fishery but they were not included in the most recent MSC assessment for this fishery since they are not considered ETP, and their landed volumes are too low to meet the 5% bycatch threshold required by the MSC Standard.

4.5 | Study limitations

A key challenge we faced in the modelling component of our study was the lack of abundance time series (or even timely health status updates) for most stocks. Further, while a suite of over 100 potential indicators to measure Canadian fishery performance have been identified (Stephenson et al., 2019), most of these are unavailable for Canadian fisheries at the stock level. Thus, for our model, we were required to select coarser ecological, socio-economic, and institutional indicators that were available for all 230 stocks. Similarly, although our base data source, the Fishery Audit, has been published annually since 2017, the average stock assessment age for species with a known status was 5.7 $\pm$4.1 years. For example, the last scientific report for our second most notable bright spot (Eastern Component 4VW + 4Xmn pollock) was published by DFO in 2012 (Stone, 2012) and the most recent full stock assessment cited in the 2022 Pacific shrimp trawl fishery management plan (Fisheries and Oceans Canada, 2022) is also over a decade old (DFO, 2012). This may in part explain some concerns raised by interviewees with Pacific coast shrimp data collection processes and quota-setting. Although this likely does not affect our model results (i.e., retained drivers), this example highlights how a mismatch could occur when it comes to how the current health of a stock is perceived by participants who completed the survey and/or interview.

We also highlight that the Fishery Audit dataset we used is more comprehensive than the list of key fish stocks included in DFO's annual Sustainability Survey for Fisheries (DFO, 2023). These differences are partly attributable to annual changes in which stocks are included in DFO's definition of 'key stock', how stocks are defined within the datasets (e.g., the DFO Sustainability Survey includes 'Shrimp trawl' as one stock, while the Fishery Audit breaks down the various Pacific shrimp species caught by trawl into 12 different stocks) and because of the taxonomic groups included (i.e., the DFO Survey includes marine mammals and salmonids, while the Fishery Audit does not) (ECCC, 2023). Still, eighteen of 25 bright and dark deviants are not included on the DFO list and only seven of 12 middle spots investigated in our study are also included in the DFO list of key stocks. These differences may partly explain the lack of attention given to some stocks in the survey portion of our study, as half of the stocks lacking responses were not included on the DFO Survey list. In general, this also presents a concern in the Canadian government's approach fisheries management, especially in the context of non-target species, many of which are currently subject to limited oversight despite their underperforming health status (see 'Bycatch' in Figure 3b).

Regarding the expert feedback components of our study, survey participants had to be knowledgeable of one of the 37 stocks identified as a bright, dark, or middle spot. This focus on deviant stocks inherent in our methodology reduced the number and diversity of respondents that could contribute to this work. While we did control for participant biases related to stock outcome by using a blind survey, any personal biases or beliefs held by respondents associated with fisheries for these stocks may affect our study. At the same time, we could not utilize the perspectives and knowledge held by individuals familiar with stocks not investigated here or individuals who did not receive our survey. For the associated analyses, our research question and the sample size of survey participants necessitated grouping survey responses by stock type rather than by respondent demographics, which meant that all perspectives were weighed equally and not differentiated by affiliation. Unfortunately, some stocks received few survey responses, which is why we pooled responses across stocks within an outlier group. While there were observable differences between dark, middle, and bright spots (Figure 4), the small sample sizes likely also limited our ability to detect statistical significance across the three fishery groups. Future research using this approach will always be dependent on the sample size and composition of outliers, as well as how many people choose to participate, but efforts to reduce potential biases and increase diversity could include a more comprehensive and targeted recruitment process and/or a longer timeframe for soliciting feedback.

5 | CONCLUSIONS

We found that positive deviants in Canadian fish stock health are subject to more robust data collection and monitoring processes when compared to their negative counterparts. Additionally, proactive sustainability incentives (including market-based programs) combined with constructive relationships between government and industry lead to better-than-expected outcomes. We further found some evidence of regional conflict between DFO scientists, managers, and fishery stakeholders and that entrenched regional power dynamics and interference by industry members may have enabled the exploitation of legislative shortcomings. This appeared especially true for stocks of high economic value that are currently overfished.

Beyond re-iterating the value of implementing existing reference points and harvest control rules, our results also suggest that one solution to remedy identified data gaps in Canadian fisheries (and associated conflict over stock assessment projections) is 100% electronic observer coverage. As discussed in Section 4.1, this appears especially valuable for fisheries with targeted and/or incidental catches of stocks in the critical zone, and this effort would also be in keeping with recent recommendations by the Auditor General of Canada related to at-sea and dockside monitoring (OAG, 2023). In addition to information required by DFO scientists for their work, one of the key challenges we faced in this study was the lack of a centralized data platform for Canadian fisheries. This finding is again consistent with the OAG (2023) suggestion that DFO must work towards amalgamating stock-level information into a national database; here we suggest the publicly facing 'StockSMART' platform used by NOAA (https://apps-st.fisheries.noaa.gov/stocksmart) as a model.

In addition to these technical solutions, improved leadership and conflict resolution, as well as balanced decision-making influence across diverse stakeholder and rightsholder groups all appear important in driving Canadian fisheries towards better outcomes. Overcoming longstanding conflicts and power imbalances can be challenging, however, especially under resource scarcity and in times of rapid environmental change. Similarly, other researchers have highlighted the importance of transitioning to a more comprehensive and inclusive approach to fisheries governance (Bennett et al., 2018; Stephenson et al., 2019). For example, the pairing of traditional western approaches with Indigenous knowledges and principles can unite historically polarized groups to act on a common objective (Reid et al., 2021). Such a pluralistic approach to fisheries management can improve existing policies (Ban et al., 2018) and bolster ecosystem stability and resilience (Frid et al., 2023).

In closing, we emphasize the benefits of using a mixed-methods positive deviance approach to identify enabling conditions of fish stock health. Notably, our findings are consistent with longstanding views regarding the importance of both good data and strong incentives for collaboration (Grafton et al., 2006; Gutierrez et al., 2011; Lubchenco et al., 2016), and recent work highlighting the additional importance of diverse stakeholder inclusion and management frameworks that balance conservation and economic agendas (Bundy et al., 2017). By taking a systematic approach focused on better-than expected outcomes, positive deviance analysis eliminates the subjectivity associated with selecting which fisheries to compare in an analysis and unlocks the rich information that may be contained in unexpected outliers. As such, this methodology may be especially useful for investigating understudied fisheries, or to identify unknown barriers to sustainability in countries that are underperforming relative to international standards. It is our hope that this interdisciplinary approach will be taken up and expanded on by others to provide deeper insights into processes and solutions that are required to transform unsustainable fisheries into ecologically and socio-economically thriving ones.

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CONFLICT OF INTEREST STATEMENT

The primary dataset used in this work was amalgamated by the non-governmental organization Oceana Canada and is publicly available from their website (www.fisheryaudit.ca). Since 2017, BW has served in a voluntary capacity as a science advisor to Oceana. During this project, LS liaised with Oceana staff to ensure data were interpreted correctly but the research questions and scope were determined independently by the authors, and they received no funding from Oceana for this work.

DATA AVAILABILITY STATEMENT

All code to perform analysis and visualize results of the stock health analysis is available at: https://github.com/gregbritten/canadian_fisheries_public. Summarized survey data from the positive deviance analysis are available from the first author upon request. Interview data are confidential to ensure participant anonymity and privacy, which is in keeping with their consent to participate in this study.

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REFERENCES

Addison, J., Blyth-Skyrme, R., & Knapman, P. (2022). *Canada Northern and Striped Shrimp Public Certification Report*. https://fisheries.msc.org/en/fisheries/canada-northern-and-striped-shrimp/@@assessments

Anonymous. (2023, September 24). *FFAW asks for quota increases, full northern cod assessment following 2023 stewardship fishery closure*.

SaltWire. https://www.saltwire.com/atlantic-canada/news/ffaw-asks-for-quota-increases-full-northern-cod-assessment-following-2023-stewardship-fishery-closure-100895014/

Aqorau, T. (2019). *Fishing for success: Lessons in Pacific Regionalism*.

Archibald, D. W., McIver, R., & Rangeley, R. (2021a). The implementation gap in Canadian fishery policy: Fisheries rebuilding and sustainability at risk. *Marine Policy*, *129*, 104490. https://doi.org/10.1016/j.marpol.2021.104490

Archibald, D. W., McIver, R., & Rangeley, R. (2021b). Untimely publications: Delayed Canadian fisheries science advice limits transparency of decision-making. *Marine Policy*, *132*, 104690. https://doi.org/10.1016/j.marpol.2021.104690

Arnold, S., & Fuller, S. D. (2017). *A decade of Marine Stewardship Council (MSC) Certification in Canada: Technical Report*. https://livingoceans.org/sites/default/files/A-Decade-of-MSC-Certification-in-Canada-Technical-Report-SeaChoice-September-2017.pdf

Atkinson, B., Blyth-Skyrme, R., Angel, J., Aldous, D., & Knapman, P. (2010). *MSC Assessment Report for The OCI Grand Bank Yellowtail Flounder Trawl*. https://fisheries.msc.org/en/fisheries/oci-grand-bank-yellowtail-flounder-trawl/@@assessments

Bailey, S. (2015, May 26). *Newfoundland and Labrador says talks at stalemate with Ottawa over fish fund*. The Globe And Mail. https://www.theglobeandmail.com/news/politics/newfoundland-and-labrador-says-talks-at-stalemate-with-ottawa-over-fish-fund/article24616519/

Ban, N. C., Frid, A., Reid, M., Edgar, B., Shaw, D., & Siwallace, P. (2018). Incorporate indigenous perspectives for impactful research and effective management. *Nature Ecology & Evolution*, *2*(11), 1680–1683. https://doi.org/10.1038/s41559-018-0706-0

Beddington, J. R., Agnew, D. J., & Clark, C. W. (2007). Current problems in the Management of Marine Fisheries. *Science*, *316*, 1713–1716. https://www.science.org

Bennett, N. J., Kaplan-Hallam, M., Augustine, G., Ban, N., Belhabib, D., Brueckner-Irwin, I., Charles, A., Couture, J., Eger, S., Fanning, L., Foley, P., Goodfellow, A. M., Greba, L., Gregr, E., Hall, D., Harper, S., Maloney, B., McIsaac, J., Ou, W., … Bailey, M. (2018). Coastal and indigenous community access to marine resources and the ocean: A policy imperative for Canada. *Marine Policy*, *87*, 186–193. https://doi.org/10.1016/j.marpol.2017.10.023

Bilefsky, D. (2020, October 20). In 'Lobster War,' Indigenous Canadians Face Attacks by Fishermen. *The New York Times*. https://www.nytimes.com/2020/10/20/world/canada/nova-scotia-lobster-war.html

Blyth-Skyrme, R., & Atkinson, B. (2014). *Fourth Annual Surveillance Report OCI Grand Bank Yellowtail Flounder Fishery*. https://fisheries.msc.org/en/fisheries/oci-grand-bank-yellowtail-flounder-trawl/@@assessments

Boyce, D. G., Fuller, S., Karbowski, C., Schleit, K., & Worm, B. (2021). Leading or lagging: How well are climate change considerations being incorporated into Canadian fisheries management? *Canadian Journal of Fisheries and Aquatic Sciences*, *78*(8), 1120–1129. https://doi.org/10.1139/cjfas-2020-0394

Boyce, D. G., Tittensor, D. P., Garilao, C., Henson, S., Kaschner, K., Kesner-Reyes, K., Pigot, A., Reyes, R. B., Reygondeau, G., Schleit, K. E., Shackell, N. L., Sorongon-Yap, P., & Worm, B. (2022). A climate risk index for marine life. *Nature Climate Change*, *12*, 854–862. https://doi.org/10.1038/s41558-022-01437-y

Boyes, T. (2018). *Shifts in Spatio-Temporal Fishing Behaviour in the Canadian Pacific Halibut Hook and Line Fishery as a Result of a Choke Species* [Masters of Resource Management]. University of Alureyri.

Branch, T. A. (2009). How do individual transferable quotas affect marine ecosystems? *Fish and Fisheries*, *10*(1), 39–57. https://doi.org/10.1111/j.1467-2979.2008.00294.x

Britten, G. L., Duarte, C. M., & Worm, B. (2021). Recovery of assessed global fish stocks remains uncertain. *Proceedings of the National Academy of Sciences of the United States of America*, *118*(31), e2108532118. https://doi.org/10.1073/pnas.2108532118

Bundy, A., Chuenpagdee, R., Boldt, J. L., de Fatima Borges, M., Camara, M. L., Coll, M., Diallo, I., Fox, C., Fulton, E. A., Gazihan, A., Jarre, A., Jouffre, D., Kleisner, K. M., Knight, B., Link, J., Matiku, P. P., Masski, H., Moutopoulos, D. K., Piroddi, C., … Shin, Y. J. (2017). Strong fisheries management and governance positively impact ecosystem status. *Fish and Fisheries*, *18*(3), 412–439. https://doi.org/10.1111/faf.12184

Charles, A. T. (1992). Fishery conflicts: A unified framework. *Marine Policy*, *16*, 379–393.

Chase, S. (2003, May 7). *Fishery fight heats up in Newfoundland*. The Globe And Mail. https://www.theglobeandmail.com/news/national/fishery-fight-heats-up-in-newfoundland/article20448995/

Chu, C. (2009). Thirty years later: The global growth of ITQs and their influence on stock status in marine fisheries. *Fish and Fisheries*, *10*(2), 217–230. https://doi.org/10.1111/j.1467-2979.2008.00313.x

Cinner, J. E., Huchery, C., MacNeil, M. A., Graham, N. A. J., McClanahan, T. R., Maina, J., Maire, E., Kittinger, J. N., Hicks, C. C., Mora, C., Allison, E. H., D'Agata, S., Hoey, A., Feary, D. A., Crowder, L., Williams, I. D., Kulbicki, M., Vigliola, L., Wantiez, L., … Mouillot, D. (2016). Bright spots among the world's coral reefs. *Nature*, *535*(7612), 416–419. https://doi.org/10.1038/nature18607

Cisneros-Montemayor, A. M., Moreno-Báez, M., Reygondeau, G., Cheung, W. W. L., Crosman, K. M., González-Espinosa, P. C., Lam, V. W. Y., Oyinlola, M. A., Singh, G. G., Swartz, W., Zheng, C. W., & Ota, Y. (2021). Enabling conditions for an equitable and sustainable blue economy. *Nature*, *591*(7850), 396–401. https://doi.org/10.1038/s41586-021-03327-3

Cochrane, K. L. (1999). Complexity in fisheries and limitations in the increasing complexity of fisheries management. *ICES Journal of Marine Science*, *56*, 917–926. http://www.idealibrary.comon

Crona, B. I., Wassénius, E., Jonell, M., Koehn, J. Z., Short, R., Tigchelaar, M., Daw, T. M., Golden, C. D., Gephart, J. A., Allison, E. H., Bush, S. R., Cao, L., Cheung, W. W. L., DeClerck, F., Fanzo, J., Gelcich, S., Kishore, A., Halpern, B. S., Hicks, C. C., … Wabnitz, C. C. C. (2023). Four ways blue foods can help achieve food system ambitions across nations. *Nature*, *616*(7955), 104–112. https://doi.org/10.1038/s41586-023-05737-x

Cvitanovic, C., Hobday, A. J., van Kerkhoff, L., Wilson, S. K., Dobbs, K., & Marshall, N. A. (2015). Improving knowledge exchange among scientists and decision-makers to facilitate the adaptive governance of marine resources: A review of knowledge and research needs. *Ocean and Coastal Management*, *112*, 25–35. https://doi.org/10.1016/j.ocecoaman.2015.05.002

Davis, N. A. (2008). Evaluating collaborative fisheries management planning: A Canadian case study. *Marine Policy*, *32*(6), 867–876. https://doi.org/10.1016/j.marpol.2008.01.001

DeAlteris, J., & Trumble, R. J. (2019). *Second Re-assessment – Final Report and Determination Canada Pacific Halibut (British Columbia) Fishery*. https://fisheries.msc.org/en/fisheries/canada-pacific-halibut-british-columbia/@@assessments

DFO. (2012). *Assessment of Inshore Shrimp Stocks along the Coast of British Columbia, 2011*.

DFO. (2020, December 3). *Canada commits to growing the blue economy at home and around the globe*. https://www.canada.ca/en/fisheries-oceans/news/2020/12/canada-commits-to-growing-the-blue-economy-at-home-and-around-the-globe.html

DFO. (2021a). *Integrated Fisheries Management Plan: Groundfish Newfoundland and Labrador Region NAFO Subarea 2 + Divisions 3KLMNO*.

DFO. (2021b, December 16). *Fisheries and Oceans Canada updates Pacific herring coast-wide harvest plan for 2021–22*. https://www.canada.ca/en/fisheries-oceans/news/2021/12/fisheries-and-oceans-canada-updates-pacific-herring-coast-wide-harvest-plan-for-2021-22.html

DFO. (2022a). *Seafisheries landed value by province, 2021*. https://www.dfo-mpo.gc.ca/stats/commercial/land-debarq/sea-maritimes/s2021pv-eng.htm

DFO. (2022b, June 1). *First Batch of 30 Major Stocks Prescribed to the Fish Stocks Provisions*. https://www.canada.ca/en/fisheries-oceans/news/2022/04/first-batch-of-30-major-stocks-prescribed-to-the-fish-stocks-provisions.html

DFO. (2022c, August 23). *Guidelines for Implementing the Fish Stocks Provisions in the Fisheries Act*. https://www.dfo-mpo.gc.ca/reports-rapports/regs/sff-cpd/guidelines-lignes-directrices-eng.htm

DFO. (2023, May 16). *Fish stocks reported on by the survey: 2021 results*. Sustainability Survey for Fisheries. https://www.dfo-mpo.gc.ca/reports-rapports/regs/sff-cpd/survey-sondage/index-en.html

ECCC. (2023). *Harvest levels of key fish stocks: Canadian environmental sustainability indicators*.

Edinger, T., & Baek, J. (2015). The role of property rights in bycatch reduction: Evidence from the British Columbia Groundfish fishery. *Fisheries Research*, *168*, 100–104. https://doi.org/10.1016/j.fishres.2015.04.001

FAO. (2022). *The State of World Fisheries and Aquaculture 2022: Towards Blue Transformation*.

FFAW. (2019). *LRP Review for Northern Shrimp Step in the Right Direction for Inshore Fishery*. Fish, Food & Allied Workers. https://ffaw.ca/the-latest/news/lrp-review-northern-shrimp-step-right-direction-inshore-fishery/

Fisheries and Oceans Canada. (2022). *Shrimp Trawl Fisheries Management Plan 2022/23*.

Fleming, A., Ogier, E., Hobday, A. J., Thomas, L., Hartog, J. R., & Haas, B. (2020). Stakeholder trust and holistic fishery sustainability assessments. *Marine Policy*, *111*, 103719. https://doi.org/10.1016/j.marpol.2019.103719

Foley, P., Mather, C., Morris, R., & Snook, J. (2017). *Shrimp Allocation Policies and Regional Development Under Conditions of Environmental Change: Insights for Nunatsiavutimmuit*. https://www.mun.ca/harriscentre/media/production/memorial/administrative/the-harris-centre/media-library/reports/FOLEY_ARF_15_16.pdf

Forrest, R. E., Stewart, I. J., Monnahan, C. C., Bannar-Martin, K. H., & Lacko, L. C. (2020). Evidence for rapid avoidance of rockfish habitat under reduced quota and comprehensive at-sea monitoring in the British Columbia pacific halibut fishery. *Canadian Journal of Fisheries and Aquatic Sciences*, *77*(8), 1409–1420. https://doi.org/10.1139/cjfas-2019-0444

Frid, A., Wilson, K. L., Walkus, J., Forrest, R. E., & Reid, M. (2023). Re-imagining the precautionary approach to make collaborative fisheries management inclusive of indigenous knowledge systems. *Fish and Fisheries*, *24*(6), 940–958. https://doi.org/10.1111/faf.12778

Gaudet, A. (2022). *Dérangement and the 2020 South Shore Lobster Dispute: A New Acadian History of Nationalism, Identity, and the Maritime Fisheries* [Bachelor of Arts]. Dalhousie University.

Godwin, S. C., Bateman, A. W., Mordecai, G., Jones, S., & Hutchings, J. A. (2023). Is scientific inquiry still incompatible with government information control? A quarter-century later. *Canadian Journal of Fisheries and Aquatic Sciences*, *80*(10), 1679–1695. https://doi.org/10.1139/cjfas-2022-0286

Government of Canada. (2022). Regulations Amending the Fishery (General) Regulations: SOR/2022-73. In *Canada Gazette, Part II* (Vol. 156, Issue 8). Government of Canada.

Grafton, R. Q., Arnason, R., Bjorndal, T., Campbell, D., Campbell, H. F., Clark, C. W., Conner, R., Dupont, D. P., Hannesson, R., Hilborn, R., Kirkley, J. E., Kompas, T., Lane, D. E., Munro, G. R., Pascoe, S., Squires, D., Steinshamn, S. I., Turris, B. R., & Weninger, Q. (2006). Incentive-based approaches to sustainable fisheries. *Canadian Journal of Fisheries and Aquatic Sciences*, *63*(3), 699–710.

Grant, T. (2021, May 10). *UN committee calls on Canada to respond to claims of racist violence against Mi'kmaw fishers*. CBC News. https://www.cbc.ca/news/canada/nova-scotia/united-nations-committee-mi-kmaw-moderate-livelihood-lobster-fishery-1.6020492

Gutierrez, N. L., Hilborn, R., & Defeo, O. (2011). Leadership, social capital and incentives promote successful fisheries. *Nature*, *470*, 386–389. https://doi.org/10.1038/nature09689

Hamelin, K. M., Hutchings, J. A., & Bailey, M. (2023). Look who's talking: Contributions to evidence-based decision-making for commercial fisheries in Atlantic Canada. *Canadian Journal of Fisheries and Aquatic Sciences*, *80*, 211–228.

Hilborn, R., Amoroso, R. O., Anderson, C. M., Baum, J. K., Branch, T. A., Costello, C., De Moor, C. L., Faraj, A., Hively, D., Jensen, O. P., Kurota, H., Little, L. R., Mace, P., McClanahan, T., Melnychuk, M. C., Minto, C., Osio, G. C., Parma, A. M., Pons, M., … Ye, Y. (2020). Effective fisheries management instrumental in improving fish stock status. *Proceedings of the National Academy of Sciences of the United States of America*, *117*(4), 2218–2224. https://doi.org/10.1073/pnas.1909726116

Hilborn, R., & Ovando, D. (2014). Reflections on the success of traditional fisheries management. *ICES Journal of Marine Science*, *71*(5), 1040–1046. https://doi.org/10.1093/icesjms/fsu034

Holm, P., & Soma, K. (2016). Fishers' information in governance—A matter of trust. *Current Opinion in Environmental Sustainability*, *18*, 115–121. https://doi.org/10.1016/j.cosust.2015.12.005

Hutchings, J. A. (2022). Tensions in the communication of science advice on fish and fisheries: Northern cod, species at risk, sustainable seafood. *ICES Journal of Marine Science*, *79*, 308–318. https://doi.org/10.1093/icesjms/fsab271

Hutchings, J. A., Baum, J. K., Fuller, S. D., Laughren, J., & VanderZwaag, D. L. (2019). *Sustaining Canadian marine biodiversity: Policy and statutory progress (2012–2019)*.

Hutchings, J. A., & Myers, R. A. (1994). What can Be learned from the collapse of a renewable resource? Atlantic cod, Gadus morhua, of Newfoundland and Labrador. *Canadian Journal of Fisheries and Aquatic Sciences*, *51*, 2126–2146. https://www.dfo-mpo.gc.ca/stats/commercial/land-debarq/sea-maritimes/s2021pq-eng.htm

Johannes, R. E., Freeman, M. M. R., & Hamilton, R. J. (2008). Ignore fishers' knowledge and miss the boat. *Fish and Fisheries*, *1*(3), 257–271. https://doi.org/10.1111/j.1467-2979.2000.00019.x

Koolman, J., Mose, B., Stanley, R., & Tragger, D. (2007). Developing an integrated commercial Groundfish strategy for British Columbia: Insights gained about participatory management. In J. Heifetz, J. DiCosimo, A. J. Gharrett, M. S. Love, V. M. O'Connell, & R. Stanley (Eds.), *Biology, assessment, and management of North Pacific rockfishes* (pp. 353–366). Alaska Sea Grant College Program.

Kourantidou, M., Hoagland, P., Dale, A., & Bailey, M. (2021). Equitable allocations in northern fisheries: Bridging the divide for Labrador Inuit. *Frontiers in Marine Science*, *8*, Article 590213. https://doi.org/10.3389/fmars.2021.590213

Levesque, B., Archibald, D., Rangeley, R., & Canada, O. (2021). *The quality of recent rebuilding plans in Canada*. https://oceana.ca/wp-content/uploads/sites/24/The-Quality-of-Recent-Rebuilding-Plans-in-Canada-2021-FINAL.pdf

Lubchenco, J., Cerny-Chipman, E. B., Reimer, J. N., & Levin, S. A. (2016). The right incentives enable ocean sustainability successes and provide hope for the future. *Proceedings of the National Academy of Sciences of The United States of America*, *113*(51), 14507–14524. https://doi.org/10.1073/pnas.1604982113

Marsh, D. R., Schroeder, D. G., Dearden, K. A., Sternin, J., & Sternin, M. (2004). The power of positive deviance. *British Medical Journal*, *329*(7475), 1177–1179. https://doi.org/10.1136/bmj.329.7475.1177

Mitchell, B., King, P., & Waterloo, C. (1984). Resource conflict, policy change and practice in Canadian fisheries management. *Geoforum*, *15*(3), 419–432.

Moore, M. (2023, March 16). *Positive signs in newest capelin stock assessment, but the tiny fish is still in the critical zone*. CBC News. https://www.cbc.ca/news/canada/newfoundland-labrador/dfo-capelin-stock-assessment-nl-2023-1.6779681

Neubauer, P., Jensen, O. P., Hutchings, J. A., & Baum, J. K. (2013). Resilience and recovery of overexploited marine populations. *Science*, *340*(6130), 347–349. https://doi.org/10.1126/science.1230441

OAG. (2016). *Sustaining Canada's Major Fish Stocks—Fisheries and Oceans Canada*. https://www.oag-bvg.gc.ca/internet/English/parl_cesd_201610_02_e_41672.html

OAG. (2023). *Monitoring Marine Fisheries Catch – Fisheries and Oceans Canada: Independent Auditor's Report*. https://www.oag-bvg.gc.ca/internet/English/parl_cesd_202311_09_e_44372.html

O'Brien, T. (2022, January 24). *DFO scientists' union says members' work in N.L. undermined by industry and political interference*. CBC News. https://www.cbc.ca/news/canada/newfoundland-labrador/dfo-scientists-union-1.6322758

Pascale, R., Sternin, J., & Sternin, M. (2010). *The power of positive deviance: How unlikely innovators solve the World's toughest problems*. Harvard Business Press.

Pauly, D., & Zeller, D. (2016). Catch reconstructions reveal that global marine fisheries catches are higher than reported and declining. *Nature Communications*, *7*(10), 244. https://doi.org/10.1038/ncomms10244

Pepin, P., King, J., Holt, C., Smith, H. G., Shackell, N., Hedges, K., & Bundy, A. (2022). Incorporating knowledge of changes in climatic, oceanographic and ecological conditions in Canadian stock assessments. *Fish and Fisheries*, *23*(6), 1332–1346. https://doi.org/10.1111/faf.12692

Pershing, A. J., Alexander, M. A., Hernandez, C. M., Kerr, L. A., Bris, A. L., Mills, K. E., Nye, J. A., Record, N. R., Scannell, H. A., Scott, J. D., Sherwood, G. D., & Thomas, A. C. (2015). Slow adaptation in the face of rapid warming leads to collapse of the Gulf of Maine cod fishery. *Science*, *350*(6262), 809–812. https://doi.org/10.1126/science.aac9819

Reid, A. J., Eckert, L. E., Lane, J. F., Young, N., Hinch, S. G., Darimont, C. T., Cooke, S. J., Ban, N. C., & Marshall, A. (2021). "Two-eyed seeing": An indigenous framework to transform fisheries research and management. *Fish and Fisheries*, *22*(2), 243–261. https://doi.org/10.1111/faf.12516

Schijns, R. (2022). *A fuller picture of the state of Canada's fisheries: Assessments for data-limited stocks*. https://oceana.ca/wp-content/uploads/sites/24/Oceana_Canada_Report_Fuller_Picture_State_Canadian_Fisheries_Data_Limited_Tools_CMSY.pdf

Schijns, R., & Rangeley, R. (2022). *2022 Fishery Audit: Unlocking Canada's Potential for Abundant Oceans*. https://doi.org/10.5281/zenodo.7277467

Schiller, L., Auld, G., Hanich, Q., & Bailey, M. (2023). Increasing industry involvement in international tuna fishery negotiations. *One Earth*, *6*(1), 41–54. https://doi.org/10.1016/j.oneear.2022.12.001

Schiller, L., Auld, G., Sinan, H., & Bailey, M. (2021). Decadal changes in international advocacy toward the conservation of highly migratory fishes. *Conservation Letters*, *14*(6), e12827. https://doi.org/10.1111/conl.12827

Selig, E. R., Kleisner, K. M., Ahoobim, O., Arocha, F., Cruz-Trinidad, A., Fujita, R., Hara, M., Katz, L., McConney, P., Ratner, B. D., Saavedra-Díaz, L. M., Schwarz, A. M., Thiao, D., Torell, E., Troëng, S., & Villasante, S. (2017). A typology of fisheries management tools: Using experience to catalyse greater success. *Fish and Fisheries*, *18*(3), 543–570. https://doi.org/10.1111/faf.12192

Simpfendorfer, C. A., & Dulvy, N. K. (2017). Bright spots of sustainable shark fishing. *Current Biology*, *27*(3), R97–R98. https://doi.org/10.1016/j.cub.2016.12.017

Singh, G. G., Cisneros-Montemayor, A. M., Swartz, W., Cheung, W., Guy, J. A., Kenny, T. A., McOwen, C. J., Asch, R., Geffert, J. L., Wabnitz, C. C. C., Sumaila, R., Hanich, Q., & Ota, Y. (2018). A rapid assessment of co-benefits and trade-offs among sustainable development goals. *Marine Policy*, *93*, 223–231. https://doi.org/10.1016/j.marpol.2017.05.030

Smith, A. D. M., Fulton, E. J., Hobday, A. J., Smith, D. C., Smith, P. S., Fulton, A. D. M., Hobday, E. J., & Smith, A. J. (2000). Scientific tools to support the practical implementation of ecosystem-based fisheries management. *International Council for the Exploration of the Sea*, *64*, 633–639. https://academic.oup.com/icesjms/article/64/4/633/641888

Soomai, S. S. (2017). The science-policy interface in fisheries management: Insights about the influence of organizational structure and culture on information pathways. *Marine Policy*, *81*, 53–63. https://doi.org/10.1016/j.marpol.2017.03.016

Spijkers, J., Morrison, T. H., Blasiak, R., Cumming, G. S., Osborne, M., Watson, J., & Österblom, H. (2018). Marine fisheries and future ocean conflict. *Fish and Fisheries*, *10*(6), 173–179. https://doi.org/10.1111/faf.12291

Stanfield, S. (2020, January 31). *DFO sets Salish Sea herring harvest rate at 20 per cent*. Comox Valley Record. https://www.comoxvalleyrecord.com/news/dfo-sets-salish-sea-herring-harvest-rate-at-20-per-cent-1604469

Stanley, R. D., Karim, T., Koolman, J., & Mcelderry, H. (2015). Design and implementation of electronic monitoring in the British Columbia groundfish hook and line fishery: A retrospective view of the ingredients of success. *ICES Journal of Marine Science*, *72*(4), 1230–1236. https://doi.org/10.1093/icesjms/fsu212

Stephenson, R. L., Wiber, M., Paul, S., Angel, E., Benson, A., Charles, A., Chouinard, O., Edwards, D., Foley, P., Lane, D., McIsaac, J., Neis, B., Parlee, C., Pinkerton, E., Saunders, M., Squires, K., & Sumaila, U. R. (2019). Integrating diverse objectives for sustainable fisheries in Canada. *Canadian Journal of Fisheries and Aquatic Sciences*, *76*(3), 480–496. https://doi.org/10.1139/cjfas-2017-0345

Stone, H. H. (2012). *Biomass Reference Points for Eastern Component Pollock (4VW+4Xmn).*

Swerdfager, T., & Armitage, D. (2023). Co-management at a crossroads in Canada: Issues, opportunities, and emerging challenges in fisheries and marine contexts. *Facets*, *8*, 1–10. https://doi.org/10.1139/facets-2022-0217

Temby, O., Rastogi, A., Sandall, J., Cooksey, R., & Hickey, G. M. (2015). Interagency trust and communication in the transboundary governance of pacific salmon fisheries. *Review of Policy Research*, *32*(1), 79–99. https://doi.org/10.1111/ropr.12108

The Bay of Fundy Herring Industry. (2022, May 4). *Bay of Fundy Herring Industry Proposes Sustainability Plan*. https://www.newswire.ca/news-releases/bay-of-fundy-herring-industry-proposes-sustainability-plan-860016560.html

Thompson, J. (2021, February 9). 'Trapped': Women Working as Fishery Observers Allege Sex Harassment, Assault at Sea. *VICE*.

Thompson, J. (2022, May 26). Docs show turmoil in DFO following fisheries harassment investigation: 'this article is horrific'. *The Narwhal*.

Thornhill-Verma, J. (2021). *Cod collapse: The rise and fall of Newfoundland's saltwater cowboys*. Nimbus Publishing Ltd.

Tigchelaar, M., Leape, J., Micheli, F., Allison, E. H., Basurto, X., Bennett, A., Bush, S. R., Cao, L., Cheung, W. W. L., Crona, B., DeClerck, F., Fanzo, J., Gelcich, S., Gephart, J. A., Golden, C. D., Halpern, B. S., Hicks, C. C., Jonell, M., Kishore, A., … Wabnitz, C. C. C. (2022). The vital roles of blue foods in the global food system. *Global Food Security*, *33*, 100637. https://doi.org/10.1016/j.gfs.2022.100637

Venebles, W., & Ripley, B. (2002). *Modern applied statistics with S* (4th ed.). Springer.

Wallace, S., Turris, B., Driscoll, J., Bodtker, K., Mose, B., & Munro, G. (2015). Canada's pacific groundfish trawl habitat agreement: A global first in an ecosystem approach to bottom trawl impacts.

Marine Policy, *60*, 240–248. https://doi.org/10.1016/j.marpol.2015.06.028

Withers, P. (2019). *Industry challenges DFO's assessment of Atlantic mackerel stocks*. CBC News. https://www.cbc.ca/news/canada/nova-scotia/dfo-mackerel-assessment-challenged-1.5110923

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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